AD/RHIC/RD-123
Revised

RHIC PROJECT

Brookhaven National Laboratory

F.M.E.A.
RHIC Cryogenics

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March 1999

F.M.E.A.
R.H.I.C. CRYOGENICS

1.0 INTRODUCTION

1.1 GENERAL

The object of a Failure Mode and Effect Analysis is to identify all the postulated modes of failure, within a system or sub-system design, so that the resultant effects can be eliminated at the earliest possible time. The system must remain safe for all reasonable postulated equipment failures or operator errors. The analysis shall be used to assess existing high risk items and the systems or sub-systems, in the design stage. The analysis will then provide us with the information needed to minimize hazardous effects due to component failure. The end result of an F.M.E.A. is increased reliability and safety.

1.2 OUTLINE

To provide assurance that all of the subsystems of the RHIC cryogenic system were covered, the analysis was carried out in concert with the design effort when possible.

1.2.1 The cognizant engineer (CE) involved in the design of their respective subsystem or component have considered the potential failure modes and their effects on the subsystem or component.

1.2.2 The failure of a component of a subsystem, causing a complete failure of the subsystem, would be viewed upon as a component failure of the system. For example, a vacuum failure of one of the valve boxes would be viewed as a failure of the valve box for the system FMEA.

1.2.3 This F.M.E.A. will review the failure modes and effects of a component failure in subsystems, and in addition will study the effect of total failure modes, of the subsystems, and their effect on the Cryogenic system as a whole.

1.2.4 The FMEA is primarily component orientated. Each component of the system should be reviewed in each possible failed state, for each mode of operation, to evaluate its possible safety consequences to the system. When the FMEA is applied to a process, with different modes of operation, the steps or operating procedures have been carefully formulated or reviewed. In addition a safety analysis work sheet, with operating mode indicated, is used as a record of the specific failures. The work sheets will include information on system or subsystem modes in order to evaluate the components effect as a function of mode. The work sheets will contain specific information as follows:

1.2.4.1 The description of failure.
1.2.4.2 Mode or phase.
1.2.4.3 The effect of this failure on the system.
1.2.4.4 Failure detection.

2.0 SCOPE

2.1 GENERAL

2.1.1 This FMEA is intended to cover the RHIC cryogenic distribution system and components.

2.2 SYSTEMS AND COMPONENTS FOR ANALYSIS

2.2.1 The broad categories that will be included in this study are as follows:

2.2.1.1 The cold helium distribution system associated with the ring magnets (valve boxes, transfer lines, etc.)

2.3 COMPONENTS REVIEWED

2.3.1 Types of components that are covered in this study include: valves, relief valves, sensors, filters, switches, gauges, interlocks, etc.

2.4 SYSTEMS OR SUBSYSTEMS NOT COVERED

2.4.1 Systems that are not a direct part of the Cryogenic System, i.e. magnet power supplies, quench protection devices, etc. will be subjected to an F.M.E.A., by others. The F.M.E.A. of these "other" systems is outside the scope of this F.M.E.A.

3.0 PROCEDURE

3.1 INTRODUCTION

3.1.1 To properly prepare an F.M.E.A. that includes the effects on the process and the potential hazards to personnel, we must systematically identify and analyze all of the possible faults.

3.2 GENERAL PROCEDURE FOR ANALYSIS

3.2.1 Identify the major systems and subsystems that in an event of failure will greatly affect the operation of the cryogenic system or could present a hazardous situation to personnel.

3.2.2 Meet with cognizant personnel, to discuss potential failure modes of equipment and systems. Compile this information (see appendix).

3.2.3 Review or establish operating procedures so that mode dependency can be established.

3.2.4 Study and list each component, in the analysis work sheets, and enter all required information. See appendix.

3.3 DETAILED PROCEDURE FOR ANALYSIS

3.3.1 As the analysis of systems differ, in that some are operational mode dependant, the detailed method is contained as a cover sheet with the analysis work sheets.

4.0 METHODOLOGY

To apply an FMEA, to the valve boxes and magnet strings, a detailed study of the valve box P&ID's and the development of general operating procedures was completed. The operating procedures covered the various modes of operation, **A to E**, below. The development of the procedures was the first exercise verifying the capability of the valve box P&ID's. Some modifications, noted below, were made before the actual FMEA. The modes studied for the analysis of the valve box and magnet strings are as follows:

A) ***Normal*** full-ring operation.

B) ***Cooldown*** of the entire machine.

C) ***Warm-up*** of the entire machine.

D) ***Warm-up*** of the sextant at ***3:00*** including: isolation, reestablishment of heat shield flow to other sextants, liquid and gas recovery via CR line, reestablishment of helium coolant to other sextants (circulator off, refrigerator supply to magnet loop to recooler JT valves to return), circulation of warm helium from compressor discharge.

E) ***Recool*** the ***3:00*** sextant with all others cold.

The following analysis work sheets cover the valve boxes and magnet strings for the modes of operation referenced above.

5.0 Results

The Project policy for the safety review of cryogenic systems is contained in RHIC SEAPPM 5.2.1. The P&IDs and the Active Components List, mentioned above in Chapter 3, Section Q.5., were the basis for two Failure Modes and Effects Analysis (FMEA) which were done for this system (see Attachments 1 and 2). The first analysis was conducted for the Normal Operating Condition, when the rings were cooled to 4K for steady-state operation. The second analysis was conducted for a single sextant warm-up, where one or more magnets required removal and replacement. In this case, RHIC operations would prefer to maintain the remainder of the machine at 4K to save energy and reduce recooling time. A warm-up of the 3 o'clock sextant was analyzed, but is representative of a warm-up of any other sextant. These analyses list the identified hazards which may result from the failure of each item of equipment in the system and assesses the risk of that event. Where this analysis resulted in action items recommended to eliminate or control the hazard, these actions have been incorporated into the design.

The Normal Operations FMEA was performed in conjunction with the design effort for the Cryogenic System Valve Boxes. The Cryogenic System Valve Boxes are the centralized controls for the distribution of cryogen at the end of each sextant. At the 6 o'clock junction, the Cryogenic System Valve Box functions were expanded to include the interface between the RHIC Refrigerator and the Collider Ring and to include the ring helium circulators. The system makes extensive use of remotely operated valves which may be controlled from the Cryogenic System Main Control Room. These valves are air-operated via solenoid controls, with the de-energized state relying upon spring force for motive power. Thus, an initial de-energized state must be assigned in order to conduct the analysis. Once RHIC commences operation, the Cryogenic System should operate in the cold state for a majority of the year, with, at most, annual shut-downs for maintenance. The initial valve state was chosen such that failures of the valves will not cause an interruption of Collider operations. The FMEA also considered isolation and warm-up of a single sextant while the rest of the system remained cold.

The analytical effort of Normal Operations was especially successful in discovering some initial design flaws which would have prevented intended operation of the Cryogenic System. These flaws were corrected prior to valve box construction, with negligible impact on system cost or schedule. The FMEA worksheets provide details regarding the failure modes and failure effects for each Cryogenic System Valve Box component. Also included in the FMEA was an analysis to determine the means by which the failure could be detected.

There were 83 functionally-distinct categories for 1875 components that were analyzed. There are no single-point failures which would result in personal injury or major system damage. This makes their probability of occurrence Extremely Remote, as defined by BNL ES&H Standard 1.3.3, *Safety Analysis Reports/Safety Assessment Documents*. There were 27 functional categories of components which would restrict or inhibit cryogen flow to a degree that, for a worst case situation, the magnets would be insufficiently cooled and might quench. However, all magnets will have a quench protection system which will de-energize power supplies and activate an energy absorbing system, and the RHIC magnets all are capable of absorbing their own energy without the potential for damage, thus making this a Negligible hazard severity (as defined by BNL ES&H Standard 1.3.3) for the mitigated condition. Three of these functional categories of failures may result in circulator failure for the worst case. However, this hazard would only be classified as Negligible, with a Remote probability of occurrence. Pressure transducers for the Cryogenic System have a capacity at least equal to the Cryogenic System design pressure of 275 psi, which mitigated a potential hazard detected in a previous FMEA. Nine functional categories of components have the potential for loss of helium gas inventory. The worst case assumes no intervention. However, a sizable gas leak would be readily detected by Cryogenic System operators, and there would be sufficient instrumentation/controls; i.e., pressure transducers, temperature sensors, remote valve operation, etc., remaining intact to prevent a significant loss of inventory. One fault would result in a relatively minor leak of inventory to atmosphere. These failures, if uncorrected by operations personnel, have the potential for a Marginal hazard, with a probability of Remote to Extremely Remote.

Four functional categories of components may affect the speed control for the cryogenic circulators. Two would cause the speed to decrease, with a potential for reduced cooling capability. Two could command speeds excessive for the circulator, leading to an overspeed. To prevent electrical overspeed of the circulator, a design criterion was established to incorporate a separate overspeed protection circuit. This criterion was implemented. These categories of failures would be Marginal, with a probability of occurrence of Remote to Extremely Remote. Two faults could cause magnets to de-energize due to loss of lead cooling. One of those faults is a manual valve, which would be detected on start-up. These hazards have a Negligible impact with a Remote probability of occurrence. Six faults could cause an imbalance of the refrigerator. A significant imbalance in the refrigerator would cause the refrigerator to be shut off from the rings in order to maintain refrigerator operation. This is not hazardous, because the rings would act like a large dewar, taking several hours to warm sufficiently that the pressure would reach relief valve settings. These potential hazards have Negligible impact, with a Remote probability of occurrence. Two faults could cause valves to not seat entirely, permitting leakage of gas. However, this would have no impact on Normal Operations. Finally, a single category of component, a relief valve, could result in a failure of piping or adjacent components which may contain cryogen. The relief valve protects the volume between two valves which interconnect adjacent process lines. However, one of the valve pairs is normally open, thereby venting the volume to a process line. The volume also includes pressure sensors. Finally, an overpressure can only occur when the volume is filled with cryogen, then warmed. Again, the volume will normally be open during warm-up to release this gas. The valves and the volume reside inside the valve box vacuum tank which will provide containment. There is no hazard from helium release because of the small volume involved. This provides classification of this hazard as Negligible with an Extremely Remote probability of occurrence.

Similarly, a FMEA was conducted for a single sextant warm-up. The analysis considered both rings warming in the affected sextant, although it likely that only one ring would require warming. Because the rings are mirrored configurations, there is no fault that could impact the other. Warming the sextant is a transient operation lasting less than 24 hours which did not warrant evaluation. However, once warmed, operations will be conducted to maintain the remainder of the sextants at about 4K. This consists of two modes for operation – one to maintain the heat shield, and the second to circulate 4K gas to keep the magnets cold. The two operations are mutually exclusive. The FMEA considers both modes in a single tabulation, where those components would have an impact on one or the other mode. A majority of the components are not involved in the warm-up operation or do not interface with the warmed-up sextant, thus have no impact on the operating state.

There were 93 functionally-distinct categories for the same 1875 components that were analyzed in the above FMEA. There are two categories of single-point failures which could result in personal injury. These are detailed in Items #84 and #89, which are failures causing the sextant isolation valves between the warm and cold sextants to open. The worst case failure assessment assumes a magnet is removed or in the process of being removed, and the open valve failure causes cryogen to be released through the open piping. This is unlikely, as the valves are lockable, and were originally designed as such because this failure mode was obvious for this scenario. Mitigation of this hazard requires that Single Sextant Warm-Up Procedures specify locking these valves in the closed position until the process piping is closed. This hazard would be classified as Catastrophic, with a probability of Impossible for the mitigated condition. There were 32 functional categories of components which would restrict or inhibit cryogen flow to a degree that, for a worst case situation, the magnets would be insufficiently cooled. The consequence is that the temperature rise will be accompanied by a pressure rise and the need to store helium inventory. This can be accomplished safely in the liquid storage area or in the gaseous storage tanks. This provides a hazard classification of Negligible, with a probability of

occurrence of Remote. Nine functional categories of components have the potential for loss of helium gas inventory, with three additional categories posing a potential thermal and/or Oxygen Deficiency hazard to personnel as well as the loss of inventory. The worst case gas leak assumes no intervention. However, a sizable gas leak would be readily detected by Cryogenic System operators, and there would be sufficient instrumentation/controls; i.e., pressure transducers, temperature sensors, remote valve operation, etc., remaining intact to prevent a significant loss of inventory. ODH systems are in place to protect personnel, rendering the mitigated hazard category Negligible, with an Extremely Remote probability of occurrence.
Nine faults could cause an imbalance of the refrigerator. A significant imbalance in the refrigerator would cause the refrigerator to be shut off from the rings in order to maintain refrigerator operation. This is not hazardous, because the rings would act like a large dewar, taking several hours to warm sufficiently that the pressure would reach relief valve settings. Finally, a single category of component, a relief valve, could result in a failure of piping or adjacent components which may contain cryogen. The relief valve protects the volume between two valves which interconnect adjacent process lines. However, one of the valve pairs is normally open, thereby venting the volume to a process line. The volume also includes pressure sensors. Finally, an overpressure can only occur when the volume is filled with cryogen, then warmed. Again, the volume will normally be open during warm-up to release this gas. The valves and the volume reside inside the valve box vacuum tank which will provide containment. There is no hazard from helium release because of the small volume involved.

AD/RHIC/RD-124

RHIC PROJECT

Brookhaven National Laboratory

Failure Mode and Effects Analysis
RHIC Cyrogenic
Liquid Storage Area

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February 1999

Failure Mode and Effects Analysis
R.H.I.C. Cryogenic
Liquid Storage Area

1.0 INTRODUCTION

1.1 GENERAL

The object of a Failure Mode and Effect Analysis (FMEA) is to identify all the postulated modes of failure, within a system or sub-system design, so that hazards from the resultant effects can be eliminated or control to an acceptable level of risk at the earliest possible time. The system must remain safe for all reasonable postulated equipment failures or operator errors. The analysis shall be used to assess existing high risk items and the systems or sub-systems, in the design stage. The analysis will then provide us with the information needed to minimize hazardous effects due to component failure. The end result of an FMEA is increased reliability and safety.

1.2 OUTLINE

To provide assurance that all of the subsystems of the RHIC cryogenic system were covered, the analysis was carried out in concert with the design effort when possible.

1.2.1 The cognizant engineer (CE) involved in the design of their respective subsystem or component has considered the potential failure modes and their effects on the subsystem or component.

1.2.2 The failure of a component of a subsystem, causing a complete failure of the subsystem, would be viewed upon as a component failure of the system. For example, a vacuum failure of one of the valve boxes would be viewed as a failure of the valve box for the system FMEA.

1.2.3 This FMEA will review the failure modes and effects of a component failure in subsystems, and in addition will study the effect of total failure modes, of the subsystems, and their effect on the Cryogenic system as a whole.

1.2.4 The FMEA is primarily component orientated. Each component of the system should be reviewed in each possible failed state, for each mode of operation, to evaluate its possible safety consequences to the system. When the FMEA is applied to a process, with different modes of operation, the steps or operating procedures have been carefully formulated or reviewed. In addition a safety analysis worksheet, with operating mode indicated, is used as a record of the specific failures. The worksheets will include information on system or subsystem modes in order to evaluate the components effect as a function of mode.

2.0 SCOPE

2.1 GENERAL

2.1.1 This FMEA is intended to cover the RHIC cryogenic Liquid Storage Area (LSA) facility and components.

2.2 SYSTEMS AND COMPONENTS FOR ANALYSIS

2.2.1 The system and components reviewed for this study are those added to the RHIC cryogenic system to provide a reserve volume of liquid helium for various operating conditions. The system is identified by RHIC Helium Storage P & ID drawing RD3A995073.

2.3 COMPONENTS REVIEWED

2.3.1 Types of components that are covered in this study include: storage dewars, valves, relief valves, burst disks, sensors (pressure, differential pressure, temperature, etc.) and gauges.

2.3.1.1 The major components which make up the LSA include the following:

- The liquid helium stowage dewars (designated Dewer #1, Dewer #2 and Dewer #3),
- The liquid nitrogen dewer (designated Dewer #4),
- The distribution system associated with the liquid nitrogen system and the helium dewars,
- The distribution system between the cryogenic supply header and the helium dewars,
- The distribution system between the cryogenic return header and the helium dewars,
- The distribution system between the cryogenic cooldown return header and the helium dewars,
- Bulk fill and Local withdrawal piping.

2.4 SYSTEMS OR SUBSYSTEMS NOT COVERED

2.4.1 Systems and component that are located on the cryogenic refrigeration and distribution system side of the LSA isolation valves have been analyzed by other analyses and will not be included in this FMEA.

2.5 SYSTEM DESCRIPTION

2.5.1 Liquid Helium Dewars

Three (3) 11,000 gallon dewars provide a storage volume for Liquid Helium (LHe) during cooldown and warmup operations of the RHIC system. The dewars contain a LHe vessel, surrounded by a Liquid Nitrogen (LN_2) shield, enclosed in a vacuum insulation. For inventory control, each LHe dewer contains a Differential Pressure Transducer (DPT) for liquid level indication along with a force transducer. Both indications are available through the cryogenic computer control system. Each LHe volume of the dewer is protected from over pressurization by use of a duel branch pressure relief valve and burst disk configuration. A 3-way ball valve is used to align the dewer to either one branch or the other. In the event of a relief valve failing to reseat or a burst disk opening, that branch can be isolated to minimize the loss of LHe without loss of over pressure protection. LHe pressure indication is available through the cryogenic computer control system. Vacuum pressure is available locally.

Dewer #1 and Dewer #2 are the same Cryenco model dewar. Dewer #3 is a Gardner model. The Cryenco dewars include a self contain small LN_2 dewer for volume control. Dewer #3 does not have an independent LN_2 dewer and relies directly on LN_2 from the LN_2 stowage dewer. The Cryenco LN_2 dewer has a DPT for level detection. Overpressure protection is provided by pressure relief valve in parallel with a check valve. The LN_2 dewer is insulated by a vacuum vessel, protected by a pressure relief valve. Overpressure in the LN_2 shield of the Gardner Dewer is provided by a float controller, vented to atmosphere by two (2) check valves in parallel. The Cryenco dewar has internal electrical heaters in the LHe vessel. The Gardner dewer has a heat exchanger in the LHe vessel which is not expected to be used by the system. Each dewer uses a burst disk (Cryenco @ 5 psig, Gardner @ 0.25 psig) for vacuum vessel overpressure protection.

2.5.2 Liquid Nitrogen Dewars Distribution lines

A 20,000 gallon Cryenco LN_2 dewar (Dewer #4) provides a storage volume of LN_2 for shielding of the LHe dewars. The dewar is also protected from overpressure by use of a duel branch pressure relief valve and burst disk configuration. A 3-way ball valve is used to align the dewer to either one branch or the other as in the LHe dewars. The dewar is enclosed in a vacuum insulation. The dewer uses dual burst disks (@ 10 psig) for vacuum vessel overpressure protection. A DPT is used for liquid level indication, available through the cryogenic computer control system. Pressure indication is also available through the cryogenic computer control system. Vacuum and nitrogen pressures are available locally. A series of manual and digitally controlled pneumatic valves allow LN_2 feed to the LHe dewars and well as LN_2 dewar operations. The LN_2 header can be isolated at both the outlet of the LN_2 dewar and inlets of the LHe dewars.

2.5.3 Liquid Helium Dewars and Cryogenic Systems Distribution lines

Each LHe dewar is connected to cryogenic system Supply (S), Cooldown Return (CR) and Return (R) at the 6:00 VJRR. These headers have been designed to the same operating pressure as the cryogenic system. Relief valves are used for over pressure protection. The Return header is configured so at each LHe dewar, flow can be at the top, branched off the same port as the Cooldown Return, or at the bottom, identified as LHe. Digitally controlled pneumatic valves provide isolation for each line at both the VJRR and at each dewar. At the isolation valve at the VJRR, each line has temperature indicators on either side of the valve and a pressure indicator (available through the cryogenic computer control system) on the LSA side of the valve. At the VJRR, digitally control valves allow cross flow between the Return/LHe header and the Cooldown Return header or the Supply header. The Supply header has a flow element/DPT system to measure the amount of flow to or from the Supply header to the LSA. The Supply header can also be cross connected by use of digitally control valves with the Cooldown Return header at Dewar #1 and Dewar #2.

3.0 PROCEDURE

3.1 INTRODUCTION

3.1.1 To properly prepare an FMEA that includes the effects on the process and the potential hazards to personnel, we must systematically identify and analyze all of the possible faults.

3.2 GENERAL PROCEDURE FOR ANALYSIS

3.2.1 Identify the major systems and subsystems that in an event of failure will greatly affect the operation of the cryogenic system or could present a hazardous situation to personnel.

3.2.2 Meet with cognizant personnel, to discuss potential failure modes of equipment and systems. Compile this information (see appendix).

3.2.3 Review or establish operating procedures so that mode dependency can be established.

3.2.4 Study and list each component, in the analysis worksheets, and enter all required information. Since this is not a complex system, causes for failures have been omitted. See appendix.

4.0 Methodology

The performance of an FMEA, a detailed study of the components identified by the LSA P & ID's and the how the system is to be used were completed. The detail operating procedures for the LSA still need to be developed using the results of the FMEA for guidance. The following assumptions were made for the FMEA:

A) *Only one independent failure will occur at a time.*

B) *The cryogenic control systems used including software have been verified.*

C) *The system only uses differential pressures to move fluids, no external pumps or compressors will be added.*

D) *The lose of use of the LSA is not a safety risk The purpose of the LSA is to provide an economical means of storing Liquid Helium. The addition of the system does not invalidate the results or conclusions of prior cryogenic system safety analyses or failure analyses.*

E) *LSA operation is not directly effected by different modes of cryogenic system operation outside of its function of either receiving or the supplying of Helium.*

5.0 Results

5.1 The Liquid Storage Area (LSA) and associated piping and control systems were analyzed to determine if failures or unintended operations could cause safety risks as defined by ES & H Standard 1.3.3. The Project policy for the safety review of cryogenic systems is contained in RHIC SEAPPM 5.2.1. The P & ID for the LSA was the basis for the FMEA. Safety issues identified in the FMEA are group and summarized.

5.1.1 Overpressure Protection:
All piping and dewars associated with the LSA were examined for protection from overpressure. The primary volume of all four (4) dewars have dual branch, redundant pressure relief valve, burst disk configuration. A 3-Way valve can be used to isolate one branch at a time, but it can not isolate both branches simultaneously. All factory set relief valves and burst disks are properly labeled. Adjustable relief valves have been tested and adjustment mechanism safety wired.

The cryogenic piping headers (Supply, Cooldown Return and Return/Liquid Helium), which are subjected to the 275 psia operating pressure of the cryogenic system, are design for that pressure and are protected by at least one pressure relief valve in all possible valve positions and system configurations. In the event of a failure of a relief valve to open, which is not the typical failure mode, these headers are isolated under normal system operations by pneumatically operated control valves. The characteristics of these valve are to unseat, under high differential pressures.

Pressure gauges, Differential Pressure Transducer and Pressure Transducers are able to be isolated from the system is a way that overpressure can develop. The safety concern would be if the piping could catastrophically rupture under these conditions. These components are not isolated during normal operation, which they are protected from overpressure. Isolation of these components would only be for specific testing or for removal. These components are attached to the system by use copper piping and threaded fittings whose failure mode is to leak under high pressure (therefore venting high pressure) or pipe splitting. In addition, the volume of piping (uninsolated so the He would be gaseous) that could be affected has been minimized. These components failure mode under high pressure is to leak, typically through soft material such as the diaphragm, also reducing pressure. Therefore, the risk of injury or damage from overpressure in these lines is low.

5.1.2 Loss of Cryogenic Fluids:
Each Dewar contains level and pressure indicators which can be read at cryogenic control stations. The LHe dewars also have pressure/weight transducers to inventory control. These redundant systems mitigate the risk of overfilling, causing a release of a cryogenic hazard (personnel/equipment contact with very cold temperatures). All dewars vent to open atmosphere, so no Oxygen Deficiency Hazard (ODH) condition be present. Only the pressure relief valves for the Supply, Cooldown Return and the Return/LHe distribution header are located in the VJRR. Since the volume of piping is significantly less than that of the cryogenic system, (which also has its relief valves in the VJRR), no ODH risk would result if the relief would vent as long as normal ventilation is present. Dewar overpressure protection includes a 3-way valve which can isolate on branch in the event of a burst disk rupture or a pressure relief valve failure to reseat. This will

minimize the release of cryogenic fluids as well as reduce loss of inventory. All remotely operated valves, including valves isolating the dewars from the distribution headers and the distribution headers from the primary cryogenic system (at the VJRR) are pneumatically operated valves which will close (normal state) upon the loss of control signal or pneumatic pressure.

5.2 Summary:

The FMEA for the LSA analyzed 186 components and their failure modes. The FMEA is document on worksheets, included as an appendix to this report. The worksheets include the following information: Component Number with its nomenclature, the valve type (if a valve), pressure setting (if a relief device), the normal function, the failure position, the effect of the failure with its associated risk, comments and if there is any redundancy associated with the component or system.

92 items were analyzed to have a routine risk, as defined by ES & H Standard 1.3.3. These would result in degraded system performance and maintenance actions. 94 items were identified as have a low risk. These items would have either the potential, in the worst case scenario, to release cryogenic fluid resulting in personnel injury or equipment damage or overpressurizing components. The release of cryogenic fluid would be into open atmosphere so no oxygen deficiency hazard would exist. These areas are not typically occupied so the probability of personnel injury is minimized. Overpressurization of components would require a minimum of two independent failures. The following is a breakdown of the low risk items.

Thirty nine (41) items involve failure of components, such as vent and fill valves, which would cause the release of cryogenic fluid. These failures include the loss of insolating vacuum of the He dewars (which would cause a dynamic venting through the relief valves), failure of relief valves or isolation valves to close, overfilling the dewar and the failure to vent a dewar while filling.

Twenty six (26) items involve overpressure of components. All sections of piping are protected from overpressure from an unisolatable relief device (either relief valve or burst disk). Two independent failures, one causing the overpressure condition, and second a failure of the relief device would be required to cause damage.

Twenty five (25) items involve failure of control or isolation valves which could lead to the undesired transfer of fluid and the overfilling of a dewar. All dewars have level detectors and the He dewars also have weight transducers to control inventory. In the event that the undesired flow was not detected and allowed to overfill a dewar, pressure relief valves and burst disks would protect the dewar.

Two (2) items involve the electric heaters found in Dewar #1 and #2. These heaters provide a means of adding heat, therefore pressure into the dewars. A failure in the heater control could result in the overpressure of the dewar. The dewars are protected by relief valves and burst disks. In the current configuration of the LSA, these heaters are not used. Pressurization of a dewar for make up fluid will use pressure from stored gaseous helium.